

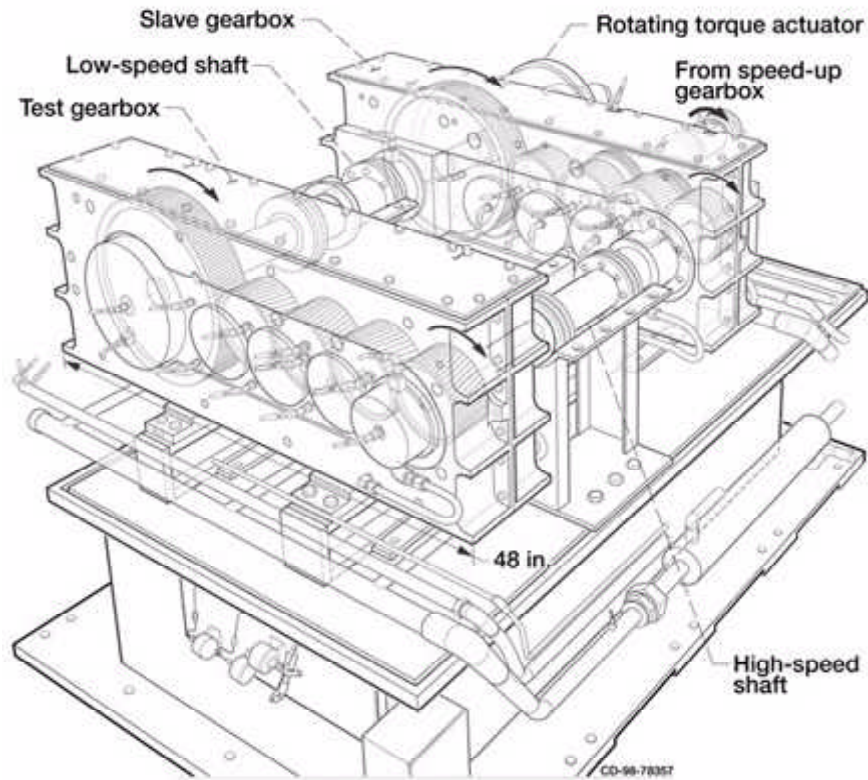
# Thermal Behavior of High-Speed Helical Gear Trains Investigated

High-speed and heavily loaded gearing are commonplace in the rotorcraft systems employed in helicopter and tiltrotor transmissions. The components are expected to deliver high power from the gas turbine engines to the high-torque, low-speed rotor, reducing the shaft rotational speed in the range of 25:1 to 100:1. These components are designed for high power-to-weight ratios, thus the components are fabricated as light as possible with the best materials and processing to transmit the required torque and carry the resultant loads without compromising the reliability of the drive system. This is a difficult task that is meticulously analyzed and thoroughly tested experimentally prior to being applied on a new or redesigned aircraft.

In some areas of gear design, no data are available internal to the manufacturer or through the open literature to improve the operational behavior of a component or system prior to prototype development. Gear-tooth bending and contact stress are usually the first considerations in designing a new transmission system. A variety of established methods exist for calculating these gear stresses, such as AGMA (American Gear Manufacturers Association) equations and finite element analysis. Conversely, the thermal behavior or thermal operational characteristics of a geared system are not well understood and are not well represented in the open literature. A design that would be successful from a bending and contact stress viewpoint can end up being a failure because of the system's thermal operational characteristics (high operational temperatures, gear tooth scoring, and high drive system losses due to high pitch line velocities).

In certain rotorcraft drive systems, such as that of tiltrotors, a helical gear train is used to orient the engine and rotor centerlines in the aircraft. This part of the drive system operates at a very high rotational speed and carries the full power of the engine during operation. Idler gears used in this type of drive system receive two thermal cycles per revolution because they act as both driver and driven gears. Because these gears have two thermal cycles per revolution, and are extremely lightweight (low thermal capacity), it can be difficult to operate the system successfully in all possible normal and emergency conditions.

A preliminary experimental investigation of the thermal behavior of high-speed helical gears was conducted at the NASA Glenn Research Center. A full-scale torque regenerative test stand was used to test a helical gear train representative of those used in tiltrotor aircraft. Power loss and temperature data from a wide range of operating conditions were measured. Power ranged up to 3730 kW (5000 hp). Drive system components representative of flight-quality hardware were used in the test program. The results attained in this initial study indicated that windage losses due to high rotational speeds were far more significant than losses due to gear meshing.

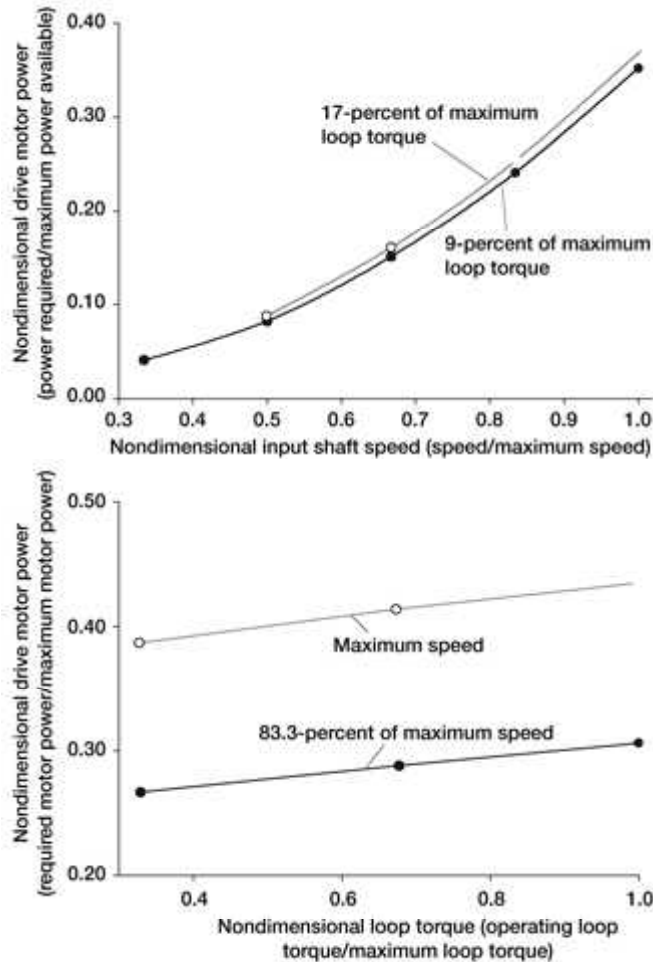


*Top: NASA Glenn Research Center's High-Speed Helical Gear Train Test Facility.*

*Bottom: Photograph of the high-speed helical gear train hardware.*

Long description of figure 1 Top: Sketch showing that the test and slave gearboxes are mirror images as far as the helical gear train is concerned. The slave gearbox has a rotating torque actuator and the shafting necessary to rotate all the gears, shafts, and bearings.

Bottom: Photograph showing the test gearbox in the partially assembled state.



*Results of preliminary tests. Top: Effect of shaft speed on drive motor power requirements at two low levels of load (torque). Bottom: Effect of torque load at two high levels of shaft speed.*

Long description of figure 2 The result of varying shaft speed from a low condition to 15 000 revolutions per minute at the input shaft. Shaft-speed- or windage-induced losses shown in this figure increase nonlinearly with the shaft speed. The second set of results show the load varied at high, but constant, shaft speed. Keeping the speed constant and increasing the load had a linear effect on the loop power requirements. Increasing the speed at a given load had a much greater effect on the loop power requirements. Thus, for this gear, system speed or windage losses are of greater concern than losses generated by gear meshing..

**Find out more about the research of Glenn's Mechanical Components Branch**  
<http://www.grc.nasa.gov/WWW/5900/5950/>.

## Reference

1. Handschuh, R.; and Kilmain, C.: Preliminary Investigation of the Thermal Behavior of High-Speed Helical Gear Trains. NASA/TM-2002-211336, ARL-TR-2661, 2002.

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